

MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR

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MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR

ABSTRACT

This project was awarded under U.S. Department of Energy (DOE) Program Solicitation DE-PS26-00NT40769 and specifically addresses Technical Topical Area 4 – Testing Novel and Less Mature Control Technologies on Actual Flue Gas at the Pilot Scale. The project team includes the Energy & Environmental Research Center (EERC) as the main contractor; W.L. Gore & Associates, Inc., as a technical and financial partner; and the Big Stone Power Plant operated by Otter Tail Power Company, which will host the field testing portion of the research.

Since 1995, DOE has supported development of a new concept in particulate control, called the advanced hybrid particulate collector (AHPC). The AHPC combines the best features of electrostatic precipitators (ESPs) and baghouses in a unique configuration, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of dust to the hopper. The AHPC provides ultrahigh collection efficiency, overcoming the problem of excessive fine-particle emission with conventional ESPs, and it solves the problem of reentrainment and re-collection of dust in conventional baghouses. The AHPC appears to have unique advantages for mercury control over baghouses or ESPs as an excellent gas–solid contactor.

The objective of the three-task project is to demonstrate 90% total mercury control in the AHPC at a lower cost than current mercury control estimates. The approach includes bench-scale batch testing that ties the new work to previous results and links results with larger-scale pilot testing with real flue gas on a coal-fired combustion system, pilot-scale testing on a coal-fired combustion system with both a pulse-jet baghouse and an AHPC to prove or disprove the research hypotheses, and field demonstration pilot-scale testing at a utility power plant to prove scaleup and demonstrate longer-term mercury control.

This project, if successful, will demonstrate at the pilot-scale level a technology that would provide a cost-effective technique to accomplish control of mercury emissions and, at the same time, greatly enhance fine particulate collection efficiency. The technology can be used to retrofit systems currently employing inefficient ESP technology as well as for new construction, thereby providing a solution to a large segment of the U.S. utility industry as well as other industries requiring mercury control.

TABLE OF CONTENTS

LIST OF FIGURES	ii
LIST OF TABLES	iv
LIST OF ACRONYMS	v
EXECUTIVE SUMMARY	vi
1.0 INTRODUCTION	1
2.0 EXPERIMENTAL	1
2.1 Objective and Goals	1
2.2 Planned Scope of Work	2
2.3 Initial Field Test with a 2.5-MW AHPC at the Big Stone Power Plant	2
3.0 RESULTS AND DISCUSSIONS	4
3.1 Coal Sampling and Analysis	4
3.2 Coal Combustion Calculation	5
3.3 Carbon Injection	6
3.4 Flue Gas Composition	8
3.5 Mercury Sampling Procedures	9
3.5.1 Ontario Hydro Mercury Speciation Method	9
3.5.2 Mercury CEM Measurements – PS Analytical Sir Galahad	12
3.6 Ontario Hydro Mercury Measurement Results	13
3.7 Mercury CEM Results	25
3.8 AHPC Operational Summary	27
4.0 CONCLUSIONS AND DISCUSSION	28

LIST OF FIGURES

1	Overview of carbon injection system	6
2	Air-Vac eductor of carbon injection system	7
3	Carbon-injecting location	7
4	Schematic of mercury speciation sample train	10
5	Sample recovery scheme for the mercury speciation sampling train	11
6	Ontario Hydro sampling train at the AHPC inlet	14
7	Ontario Hydro sampling at the AHPC outlet	14
8	Day 1 – mercury species concentration in flue gas across the AHPC	17
9	Day 1 – percentage of mercury species distribution in flue gas across the AHPC	17
10	Day 1 – mercury species collection efficiency in AHPC mode	18
11	Day 2 – mercury species concentration in flue gas across the AHPC unit in AHPC mode	18
12	Day 2 – mercury species collection efficiency in AHPC mode	19
13	Day 3 – mercury species concentration in flue gas across the AHPC unit in pulse-jet mode	20
14	Day 3 – mercury species collection efficiency in pulse-jet mode	20
15	Day 4 – mercury species concentration in flue gas across the AHPC unit in AHPC mode	22
16	Day 4 – mercury species collection efficiency in AHPC mode	22
17	Day 5 – mercury species concentration in flue gas across the AHPC unit at Big Stone in both AHPC and pulse-jet mode	23
18	Day 5 – mercury species collection efficiency under AHPC and pulse-jet mode	23

Continued . . .

LIST OF FIGURES (continued)

19	Conversion system CEM mercury sampling	25
20	PS Analytical mercury analyzer	26
21	Hg species measurement by CEM – Day 3	26
22	Hg species measurement by CEM – Day 4	27
23	Hg species measurement by CEM – Day 5	28

LIST OF TABLES

1	Summary of Mercury, Gas, and Solids Samples Taken	4
2	Coal Mercury Analysis	5
3	Coal Analysis for the Big Stone Power Plant	5
4	Summary of the Flue Gas Compositions During the 5-day Sampling	8
5	Summary of the Flue Gas Compositions During the 5-Day Sampling	9
6	HCl and SO ₃ Analysis in the Flue Gas	9
7	Sample Train Components – EPA Method 17 Configuration	10
8	Dust Loading at the AHPC Inlet and Outlet and the Calculated Collection Efficiency . .	15
9	Summary of Ontario Hydro Mercury Results	16
10	Mercury Concentration in Fly Ash	24

LIST OF ACRONYMS

AF	atomic fluorescence
AHPC	advanced hybrid particulate collector
A/C	air-to-cloth
BCI	bag-cleaning interval
CEM	continuous emission monitor
CVAAS	cold-vapor atomic absorption spectroscopy
DOE	Department of Energy
EERC	Energy & Environmental Research Center
EPA	Environmental Protection Agency
ESP	electrostatic precipitator
FGD	flue gas desulfurization
LOI	loss on ignition
PRB	Powder River Basin
PTC	particulate test combustor
SG	Smith Greenburg

MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR

EXECUTIVE SUMMARY

Since 1995, the U.S. Department of Energy (DOE) has supported development of a new concept in particulate control, called the advanced hybrid particulate collector (AHPC). The AHPC combines the best features of electrostatic precipitators (ESPs) and baghouses in a unique configuration, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of dust to the hopper.

The objective of this project is to demonstrate 90% total mercury control with commercially available sorbents in the AHPC at a lower cost than current mercury control estimates. The approach includes three levels of testing: 1) bench-scale batch testing that ties the new work to previous results and links results with larger-scale pilot testing with real flue gas on a coal-fired combustion system, 2) pilot-scale testing on a previously proven combustion system with both a pulse-jet baghouse and an AHPC to prove or disprove the research hypotheses, and 3) field demonstration pilot-scale testing at a utility power plant to prove scaleup and demonstrate longer-term mercury control.

During the first quarter of the project, initial bench-scale testing was completed, and plans were made for an initial field test earlier than planned in the original schedule.

The bench-scale results were in good agreement with previous data. This means that the planned work based on the previous results is still valid and that no changes to the overall experimental approach are necessary at this time.

Results show that the SO₂ and NO₂ concentration effects are additive and have a significant effect on sorbent performance. This finding should facilitate predicting sorbent performance in real systems when the SO₂ and NO₂ concentrations are known.

Testing with the 2.5-MW AHPC at Big Stone was not scheduled to begin until early 2002 after completing the first pilot-scale tests. However, the project team decided to complete an initial field test the first week of November 2001 prior to the pilot-scale tests at the EERC. By doing initial testing in November, mercury sampling in the worst part of the winter could be avoided. The plan is that mercury control testing at Big Stone will then resume in the spring of 2002, and the completion of the field testing within the planned schedule is expected.

Results from the initial field test with the Big Stone AHPC showed that:

- The average inlet mercury speciation for seven samples was 55.4% particulate bound, 38.1% oxidized, and 6.4% elemental. The high level of particulate-bound mercury and oxidized mercury was somewhat surprising because for western PRB coals lower levels of particulate-bound mercury and oxidized mercury are more typical. However, significant capture of mercury by the fly ash has been observed in previous EERC pilot

tests as well as a number of coal-fired plants burning western fuels. Possible factors that determine the level of particulate-bound and oxidized mercury include coal type, boiler type, HCl (as well as other flue gases), temperature, and amount of carbon in the fly ash. The current level of understanding of how these factors work together is insufficient to explain the observed mercury speciation for individual plants.

- A carbon injection rate of 1.5 lb/million acf corresponds to a carbon-to-mercury ratio of approximately 2500 for the measured inlet mercury. With this carbon injection rate, from 91% to 97% total mercury collection efficiency was achieved, compared to 49% removal for the baseline case. Even though the carbon addition rate was low, the carbon was highly effective at removing mercury. The data show that the carbon was effective at removing both elemental and oxidized mercury.
- These short-term tests are highly encouraging because they prove that excellent mercury removal can be achieved with very low addition rates of carbon injected upstream of the AHPC. Further testing is needed to demonstrate that the high level of mercury removal can be maintained over the longer term and that the carbon injection will not have any adverse effect on the longer-term operation of the AHPC.

MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR

1.0 INTRODUCTION

This project was awarded under U.S. Department of Energy (DOE) Program Solicitation DE-PS26-00NT40769 and specifically addresses Technical Topic Area 4 – Testing Novel and Less Mature Control Technologies on Actual Flue Gas at the Pilot Scale. The project team includes the Energy & Environmental Research Center (EERC) as the main contractor; W.L. Gore & Associates, Inc., as a technical and financial partner; and the Big Stone Power Plant operated by Otter Tail Power Company, which will host the field testing portion of the research.

Since 1995, DOE has supported development of a new concept in particulate control, called the advanced hybrid particulate collector (AHPC). The AHPC combines the best features of electrostatic precipitators (ESPs) and baghouses in a unique configuration, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of dust to the hopper. The AHPC provides ultrahigh collection efficiency, overcoming the problem of excessive fine-particle emission with conventional ESPs, and it solves the problem of reentrainment and re-collection of dust in conventional baghouses. In Phase II of the DOE-funded AHPC project, a 2.5-MW-scale AHPC was designed, constructed, installed, and tested at the Big Stone Power Plant. For Phase III, further testing of an improved version of the 2.5-MW-scale AHPC at the Big Stone Power Plant was conducted to facilitate commercialization of the AHPC technology. The AHPC appears to have unique advantages for mercury control over baghouses or ESPs as an excellent gas–solid contactor.

The objective of this project is to demonstrate 90% total mercury control with commercially available sorbents in the AHPC at a lower cost than current mercury control estimates. The approach includes three levels of testing: 1) bench-scale batch testing that ties the new work to previous results and links results with larger-scale pilot testing with real flue gas on a coal-fired combustion system, 2) pilot-scale testing on a previously proven combustion system with both a pulse-jet baghouse and an AHPC to prove or disprove the research hypotheses, and 3) field demonstration pilot-scale testing at a utility power plant to prove scaleup and demonstrate longer-term mercury control.

2.0 EXPERIMENTAL

2.1 Objective and Goals

The overall project objective is to demonstrate 90% total mercury control with commercially available sorbents in the AHPC at a lower cost than current mercury control estimates.

Test goals include the following:

- Determine if the bench-scale mercury breakthrough results can be duplicated when real flue gas is sampled.
- Compare the level of mercury control with sorbents under similar conditions at the 55-kW pilot scale between the AHPC and a pulse-jet baghouse.
- Demonstrate 90% mercury capture for both a western subbituminous and an eastern bituminous coal.
- Demonstrate mercury capture with the 2.5-MW AHPC at Big Stone.
- Demonstrate 90% mercury capture over a longer time (3 months) with the 2.5-MW AHPC at Big Stone.

2.2 Planned Scope of Work

To meet the objectives, the work was organized into five tasks:

- Task 1: Project Management, Reporting, and Technology Transfer
- Task 2: Bench-Scale Batch Testing
- Task 3: Pilot-Scale Testing
- Task 4: Field Demonstration Pilot Testing
- Task 5: Facility Removal and Disposition

2.3 Initial Field Test with a 2.5-MW AHPC at the Big Stone Power Plant

According to the planned work, testing with the 2.5-MW AHPC at Big Stone Power Plant was not scheduled to begin until early 2002 after completing the first pilot-scale tests. However, the project team decided to conduct an initial field test the first week of November 2001 prior to the pilot-scale tests at the EERC. There were several reasons for performing an initial early test:

- Delay in implementing the overall program by five months resulted in moving the whole schedule back by five months. With the original proposed work, the field testing would have begun in the summer. This would have prevented some of the weather problems associated with mercury sampling outside in the winter. By doing initial testing in November, we avoided having to begin the mercury sampling in the worst part of the winter. It is expected that the mercury control testing at Big Stone will then resume in the spring of 2002, and the completion of the field testing within the planned schedule should still be possible.
- A full-scale retrofit of an AHPC at Big Stone was recently announced by DOE as one of the projects selected under the DOE Power Plant Improvement Initiative. Because design of this project must begin immediately, it is imperative to have as much information available as possible. By completing this initial field test early, additional

information on AHPC performance with carbon injection should facilitate final design of the full-scale Big Stone AHPC.

- Since no mercury sampling has previously been completed at the Big Stone Power Plant, early baseline data on the actual inlet mercury concentration and speciation should help in finalizing the EERC pilot plant testing. For example, if higher-than-expected fly ash capture of mercury were seen at Big Stone, that would have to be considered in planning the pilot plant tests.

The field test at Big Stone was completed the week of November 5–10, 2001, with baseline testing on the first day, followed by carbon injection in both AHPC and pulse-jet operational modes for the remainder of the week. The starting carbon addition rate was set at 24 kg of carbon sorbent/million m³ of flue gas (1.5 lb of carbon sorbent/million acf), with the plan that it could be increased if necessary to achieve good mercury control. However, over 90% mercury control was seen at this carbon addition rate so no testing was completed at higher carbon concentrations.

A total of four Ontario Hydro mercury measurement samples were taken for each day, including both at the inlet and outlet of the AHPC. Two mercury continuous emission monitors (CEMs) provided additional information on the inlet and outlet mercury concentrations during the last three days of testing.

The first day was a baseline test in AHPC mode with no carbon injection where the AHPC was held at a constant A/C ratio of 3.0 m/min (10 ft/min), the bags were cleaned on a constant timed 20-min interval, and the ash hopper was emptied once per hour.

For the second day, conditions were identical except for carbon addition at a rate of 24 kg of carbon sorbent/million m³ (1.5 lb of carbon sorbent/million acf). The DARCO FGD carbon used was obtained from Norit Americas and is commercially available. The carbon addition was controlled with a K-Tron powder feeder and was injected pneumatically at a single point into the center of the 0.610 m (24-in)-diameter inlet duct.

For the third day, the AHPC was operated with carbon injection as a pulse-jet baghouse at an air-to-cloth (A/C) ratio of 1.5 m/min (5 ft/min), or one half the flow rate of the previous two days. To keep the same carbon-to-flue gas ratio of 24 kg of carbon sorbent/million m³ (1.5 lb of carbon sorbent/million acf), the carbon feed rate was set to half the previous level.

The fourth day was a repeat of Day 2 where the unit was again operated in AHPC mode with carbon injection at 24 kg of carbon sorbent/million m³ (1.5 lb of carbon sorbent/million acf).

For the fifth day of testing the unit was operated with carbon injection in both AHPC and pulse-jet modes, but with both at an A/C ratio of 1.5 m/min (5 ft/min). This test was completed to allow for a valid comparison between the AHPC and pulse-jet modes without changing the residence time or temperature.

For all of the tests with carbon, the sorbent was injected only during the day, and after completing the mercury sampling, the carbon was shut off overnight to allow the unit to return to baseline conditions prior to starting carbon injection the next day.

A summary of the mercury, solids, and flue gas sampling is given in Table 1.

Table 1. Summary of Mercury, Gas, and Solids Samples Taken

Ontario Hydro
Day 1 – Two Pairs of Simultaneous Inlet and Outlets
Days 2–4 – One Inlet and Three Outlets
Day 5 – Two Pairs of Simultaneous Inlet and Outlets
Mercury CEM
Continuous Sampling with Two PS Analytical Mercury CEMs on Days 3–5
SO ₃
Three Inlets Total
HCl
Three Inlets Total
SO ₂ , NO, NO ₂ , CO, CO ₂ , O ₂
Select Sampling each Day at Both Inlet and Outlet with Portable Ecom Gas Analyzer
Coal
One Sample Per Day
AHPC Hopper Ash
Day 1 – Three Total
Days 2–4 – One Baseline Before Starting Carbon Injection and Three Corresponding to the End of Each Outlet OH Sample
Day 5 – One Baseline Before Starting Carbon Injection and Two Corresponding to the End of Each Outlet OH Sample

3.0 RESULTS AND DISCUSSIONS

3.1 Coal Sampling and Analysis

A 4 L (1-gallon) grab sample of coal was collected each day from the coal feed conveyor by Big Stone Power Plant personnel. Since some supplementary corn was also being burned, the coal sample was screened to remove the corn and then analyzed for mercury. The mercury analysis for the five coal samples is shown in Table 2 to have a mean value of 0.126 µg/g, while a single analysis of the corn indicates almost no mercury originated from the corn. Ultimate and proximate analysis for the coal sample from Day 5 is shown in Table 3.

Table 2. Coal Mercury Analysis

Sample	Hg Concentration, dry coal basis, µg/g
Day 1	0.127
Day 2	0.122
Day 3	0.105
Day 4	0.149
Day 5	0.125
Mean	0.126
Corn Screened from Feed Coal	<0.001

Table 3. Coal Analysis for the Big Stone Power Plant

Proximate Analysis	% As Sampled	% Moisture Free
Moisture Content	29.3	NA
Volatile Matter	33.92	47.96
Fixed Carbon	31.57	44.67
Ash	5.21	7.37
Ultimate Analysis		
Hydrogen	6.48	4.57
Carbon	49.46	69.93
Nitrogen	0.77	1.09
Sulfur	0.38	0.54
Oxygen	37.69	16.50
Ash	5.21	7.37
Heating Value, Btu/lb	8607	12174

3.2 Coal Combustion Calculation

From the ultimate analysis, a theoretical combustion calculation was completed to determine the theoretical mercury concentration in the inlet flue gas. From the combustion calculation, the coal should produce 5.89 m³ of dry flue gas per kg (94.3 scf of dry flue gas per lb) of coal normalized to 3.0% oxygen, which corresponds to a theoretical inlet mercury concentration of 15.1 µg/Nm³ of dry flue gas at 3.0% O₂. The theoretical inlet mercury value is somewhat higher than the 11.0 to 13.3 µg/Nm³ inlet total mercury concentrations measured by the Ontario Hydro method. Possible reasons for the difference are discussed later in this report.

3.3 Carbon Injection

The DARCO FGD activated carbon is a commercially available sorbent produced by Norit Americas. DARCO FGD powdered activated carbon is a lignite coal-base activated carbon manufactured specifically for the removal of heavy metals and other contaminants typically found in incinerator flue gas emission streams. It has a surface area of 600 m²/g and has been proven in numerous full-scale operating facilities to be highly effective for the removal of gaseous mercury, dioxins (PCDD) and furans (PCDF). Its open pore structure and fine-particle size permit rapid adsorption, which is critical for high performance in flue gas streams where contact times are short.

DARCO FGD is a fine-flowing powdered carbon with minimal caking tendencies, which makes it ideal for automatic dosing systems with dry or wet injection. It is manufactured with a very high ignition temperature to permit safe operation at the elevated temperatures inherent in incinerator flue gas streams. This is a carbon that has been previously investigated by the EERC and other researchers for mercury control from coal-fired boilers.

The carbon was fed with a K-Tron dual-screw feeder at a rate of 24 kg of carbon sorbent/million m³ (1.5 lb of carbon sorbent/million acf), which corresponds to 0.29 kg/hr (0.65 lb/hr) at an A/C ratio of 3.0 m/min (10 ft/min) and 0.15 kg/hr (0.325 lb/hr) at an A/C ratio of 1.5 m/min (5 ft/min). The carbon feeder was located in the enclosed area of the AHPC below the hopper (Figures 1 and 2). From the screw feeder, the carbon was introduced into an Air-Vac eductor that was driven by compressed air. From the outlet of the eductor, the carbon was then transported approximately 6.1 m (20 ft) through 0.019-m (0.75-in.) stainless steel tubing to the elbow location of the inlet piping (Figure 3).



Figure 1. Overview of carbon injection system.



Figure 2. Air-Vac eductor of carbon injection system.



Figure 3. Carbon-injecting location.

Approximately 0.9 m (3 ft) of straight tubing extended inside the duct so that the carbon was injected directly upstream at a single point in the center of the 0.610-m (24-in.)-diameter inlet pipe.

The feeder was calibrated prior to the start of carbon injection and again at the end of each day. In addition, the weight of carbon added during a day was divided by the time of injection to provide an average feed rate. According to the calibration data and weight-of-added-carbon data, the feeder appeared to provide a very steady and consistent feed rate within a few percent of the target rate. The carbon feed and injection system worked very well, and there were no problems with inconsistent feeding or plugging of the feeder or injection system.

3.4 Flue Gas Composition

Flue gas composition was measured each day both at the AHPC inlet and outlet by using a portable Ecom gas analyzer which provided the concentrations of O₂, CO₂, CO, NO, NO₂, and SO₂ in the flue gas on a dry basis. The results for the 5-day sampling are listed in Table 4. Because of the use of low-sulfur coal of the Cordero Rojo complex, the SO₂ concentration in the flue gas was low, ranging from 165 to 299 ppm. The NO and NO₂ concentrations in the flue gas were 499–575 ppm for NO and only 1–4 ppm for NO₂. Gas concentrations normalized to a 3% O₂ level are shown in Table 5. Three SO₃ samples (by using selective condensation method) and three HCl samples (using U.S. Environmental Protection Agency [EPA] Method 26) were collected at the AHPC inlet during the 5-day test. The samples were analyzed and the results were normalized to 3% O₂ dry flue gas, as shown in Table 6.

Table 4. Summary of the Flue Gas Compositions During the 5-day Sampling (dry basis)

		O ₂ , %	CO ₂ , %	CO, ppm	NO, ppm	NO ₂ , ppm	SO ₂ , ppm
Day 1	In	6.2	13.1	1	509	4	165
	Out	5.1	14.1	1	543	3	238
Day 2	In	4.9	14.3	!	545	2	252
	Out	5.0	14.2	10	531	2	247
Day 3	In	5.3	13.9	2	575	2	251
	Out	5.3	13.9	1	514	3	248
Day 4	In	5.2	!	!	545	2	260
	Out	5.3	!	4	499	1	299
Day 5	In	5.1	14.1	2	541	2	226
	Out	5.5	13.8	1	523	3	201

Table 5. Summary of the Flue Gas Compositions During the 5-Day Sampling (dry basis normalized to 3% O₂)

		O ₂ , %	CO ₂ , %	CO, ppm	NO, ppm	NO ₂ , ppm	SO ₂ , ppm
Day 1	In	3.0	15.9	1.2	619.0	4.9	201
	Out	3.0	16.0	1.1	614.7	3.4	269
Day 2	In	3.0	16.0	!	609.3	2.2	282
	Out	3.0	16.0	11	597.4	2.2	278
Day 3	In	3.0	16.0	2.3	659.2	2.3	288
	Out	3.0	16.0	1.1	589.3	3.4	284
Day 4	In	3.0	!	!	620.9	2.3	296
	Out	3.0	!	4.6	572.1	1.1	343
Day 5	In	3.0	16.0	2.3	612.4	2.3	256
	Out	3.0	16.0	1.2	607.4	3.5	233

Table 6. HCl and SO₃ Analysis in the Flue Gas, ppm dry at 3% O₂

Gas	Sample 1	Sample 2	Sample 3
HCl	9.12	10.12	9.95
SO ₃	0.41	0.61	0.65

3.5 Mercury Sampling Procedures

3.5.1 Ontario Hydro Mercury Speciation Method

For this method, a sample is withdrawn from the flue gas stream isokinetically through the filtration system, which is followed by a series of impingers in an ice bath. A schematic of the sample train is shown in Figure 4, and Table 7 presents a list of sample train components. Particulate-bound mercury is collected on the front half and filter; oxidized mercury is collected in impingers containing 1 N potassium chloride solution; and elemental mercury is collected in one impinger containing a 5% nitric acid and 10% peroxide solution and in three impingers containing a solution of 10% sulfuric acid and 4% potassium permanganate. An impinger containing silica gel collects any remaining moisture. Quartz fiber filters were used as the filter media for the testing, and the filter holder was glass. A heated Teflon line was used between the probe and impinger train.

Figure 5 is a schematic of the sample recovery procedure for the impinger train. The samples were recovered into precleaned glass bottles with vented Teflon-lined lids for submission to the laboratory. The following sample fractions were recovered (specific rinse solutions are contained in the method):

- Container 1 – sample filter
- Container 2 – front-half rinse (includes all surfaces upstream of the filter)

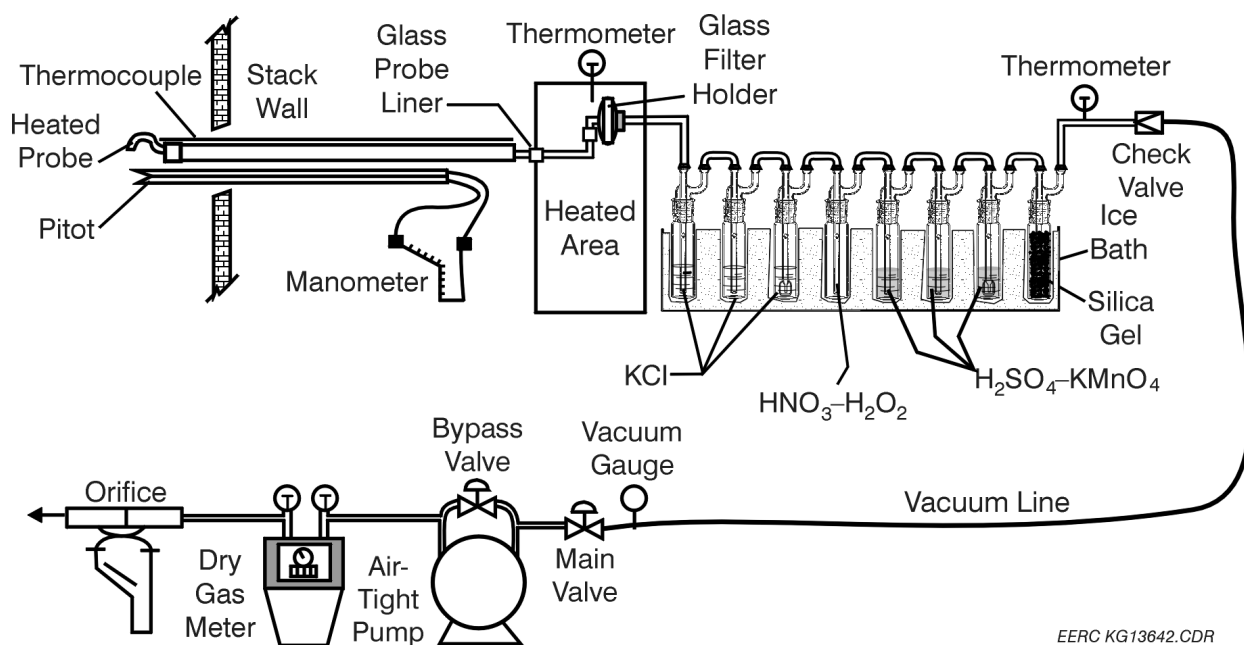


Figure 4. Schematic of mercury speciation sample train.

Table 7. Sample Train Components – EPA Method 17 Configuration

Component	Details
Nozzle	Quartz
Filter	Quartz in glass
Probe	Quartz heated to a minimum temperature of 120EC (338EF)
Connector Line	Teflon line used to connect from probe to impingers – heated to a minimum of 120EC (338EF)
Impingers 1 and 2	1 N KCl solution; modified Smith Greenburg (SG) impinger
Impinger 3	1 N KCl solution; standard SG impinger
Impinger 4	5% nitric acid–10% hydrogen peroxide; modified SG impinger
Impingers 5 and 6	10% sulfuric acid–4% potassium permanganate; modified SG impinger
Impinger 7	10% sulfuric acid–4% potassium permanganate; standard SG impinger
Impinger 8	Silica gel; modified SG impinger

- Container 3 – Impingers 1 through 3 (KCl impingers) and rinses
- Container 4 – Impinger 4 (HNO₃–H₂O₂ impinger) and rinses
- Container 5 – Impingers 5 through 7 (H₂SO₄–KMnO₄ impingers) and rinse
- Silica Gel – Impinger 8 (silica gel impinger) (note that this sample is weighed for moisture determination and is not included in the mercury analysis)

1. Rinse filter holder and connector with 0.1N HNO_3 .
2. Add 5% w/v KMnO_4 to each impinger bottle until purple color remains.
3. Rinse with 10% v/v HNO_3 .
4. Rinse with a very small amount of 10% w/v $\text{NH}_2\text{OH}\cdot\text{H}_2\text{SO}_4$ if brown residue remains.
5. Final rinse with 10% v/v HNO_3 .

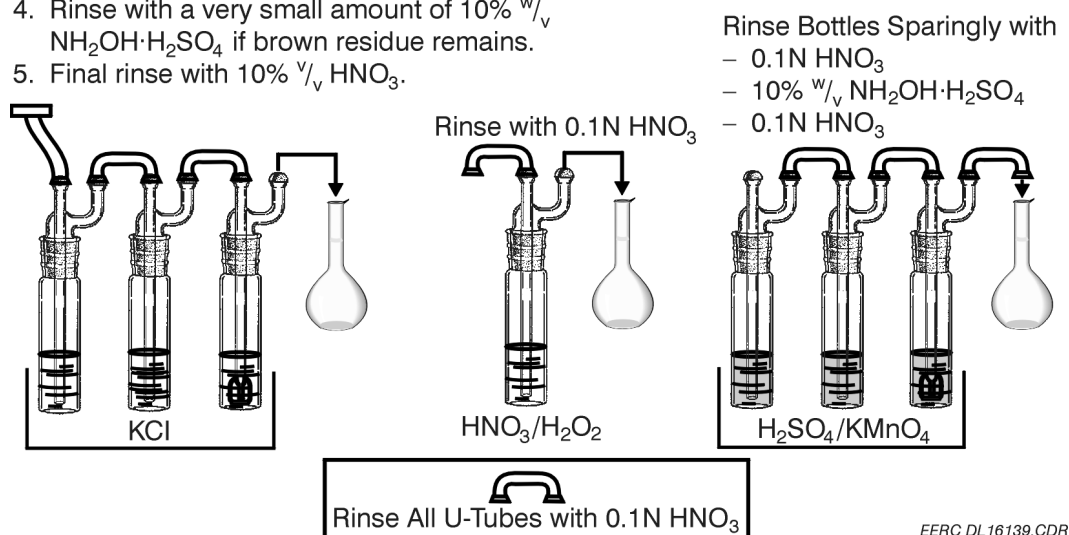


Figure 5. Sample recovery scheme for the mercury speciation sampling train.

The sample fractions were prepared and analyzed as specified in the method and summarized below:

- *Ash Sample* (Containers 1 and 2) – The particulate catch was digested and analyzed using EPA Method 3051 with subsequent analysis using EPA Method 7471A.
- *KCl Impingers* (Container 3) – The impingers were prepared using H_2SO_4 , HNO_3 , and KMnO_4 solutions as specified in the method.
- *HNO_3 – H_2O_2* (Container 4) – The impinger solution was prepared using HCl and KMnO_4 solutions as specified in the method.
- *H_2SO_4 – KMnO_4 Impingers* (Container 5) – The impinger solution was prepared using hydroxylamine sulfate as specified in the method.

Each prepared fraction was analyzed for total mercury by cold-vapor atomic absorption (CVAAS). CVAAS is a method based on the absorption of radiation at 253.7 nm by mercury vapor. The mercury is reduced to the elemental state and aerated from solution in a closed system. The mercury vapor passes through a cell positioned in the light path of an atomic absorption spectrometer. Mercury concentration is proportional to the indicated absorbance. A soda-lime trap and a magnesium perchlorate trap were used to precondition the gas before it entered the absorption cell.

3.5.2 Mercury CEM Measurements – PS Analytical Sir Galahad

The Sir Galahad analyzer can be used in a variety of gaseous media including combustion flue gas. The analyzer is based on the principle of atomic fluorescence (AF), which provides an inherently more sensitive signal than atomic absorption. The system uses a gold-impregnated silica support for preconcentrating the mercury and separating it from potential interferences that degrade sensitivity.

The Sir Galahad requires a four-step process to obtain a flue gas mercury measurement. In the first step, 2 L of flue gas is pumped through a gold trap which is maintained at a constant temperature. Before the mercury is desorbed from the gold trap, a flushing step is initiated to remove any flue gas that may be present because it has a damping effect on the mercury fluorescence. When this is completed, the analysis step begins. The heating coil is activated, and the gold trap is heated to approximately 500EC (932EF). This desorbs the mercury from the trap, and the mercury is carried into the fluorescence detector. The gold trap is rapidly cooled by pumping argon over it, in preparation for the next sample. The total time for the entire process is about 5 minutes per sample.

The system was calibrated using Hg^0 as the primary standard. The Hg^0 is contained in a closed vial which is held in a thermostatic bath. The temperature of the mercury is monitored, and the amount of mercury is calculated using vapor pressure calculations. Typically, the calibration of the unit has proven stable over a 24-hr period.

Whether the CEM uses CVAA or AF to measure mercury, some form of gas pretreatment is necessary before accurate measurement of total mercury (or speciated mercury) can be accomplished. For the CVAA-type systems, only Hg^0 can be directly analyzed. Therefore, all mercury forms in the flue gas must be converted to Hg^0 .

For the AF CEMs, a pretreatment/conversion system is also needed, but for a different reason. Both Hg^+ and Hg^0 collect on the gold trap; however, if HCl and NO_2 are present in the flue gas, the gold trap is permanently poisoned. To prevent this, since the HCl is much easier to remove than NO_2 , the HCl is removed prior to the flue gas passing through the gold trap. Also, if the instrument is to be used to provide mercury speciation data, then the Hg^+ must be removed from the gas stream so that the Hg^0 concentration can be measured.

For several years, the EERC has been working on the development of pretreatment/conversion systems for both CVAA- and AF-type mercury CEMs. The system that is currently used by the EERC consists of three primary parts:

1. An acid gas trap that removes the SO_2 and HCl without removing any of the mercury
2. A SnCl_2 gas-liquid separator to convert all Hg^+ to Hg^0
3. A gas-liquid separator that removes Hg^+ without removing Hg^0

Depending on which side of the pretreatment system the flue gas is passed through, either only Hg^0 or total mercury is measured.

3.6 Ontario Hydro Mercury Measurement Results

Ontario Hydro sampling trains were set up at the AHPC inlet and outlet to measure mercury species concentrations in the flue gas. Figure 6 shows the inlet sampling location which was 6.1 m (20 ft) upstream of the carbon injection location. A heated Teflon line was used between the probe and impinger train. The target sampling time was 2 hours. The flue gas was isokinetically pulled through the filtration system to remove fly ash from flue gas. The particle-free flue gas then passed through a series of impingers to capture elemental and oxidized mercury followed by a silica gel-filled impinger where the moisture and SO₂ were removed. The dry flue gas exiting the impinger was conveyed through a control module to measure the flow rate and the gas temperature. The outlet sampling location was just before the flue gas entered the fan, as shown in Figure 7. Since the Ontario Hydro method uses isokinetic sampling to measure mercury concentration in fly ash particles, it also provides information on dust loading in the flue gas. As shown in Figure 6, the inlet sampling location was around 1.5 m (5 ft) downstream of an elbow where flue gas had a 90 degree change of flow direction, which may result in a nonuniform fly ash distribution in the duct cross section. Some of the larger-sized fly ash particles may concentrate in the lower part of the duct because of their greater inertia, causing a lower dust-loading measurement than the real value in the system. A biased dust-loading measurement may result in slight underestimations of both particle collection efficiency and total mercury capture efficiency.

The AHPC unit was operated at an A/C ratio of 3.0 m/min (10 ft/min) without carbon injection on the Day 1 test. Two pairs of simultaneous inlet and outlet Ontario Hydro samples were collected and sent back to the EERC the same day for mercury species analysis. The analysis data showed higher-than-expected mercury concentrations in the sampling solutions: KCl, H₂O₂, and KMnO₄. The field blank samples also demonstrated high mercury concentration, indicating contamination occurred. Not knowing the source of mercury contamination, the mercury-sampling tests were carried out on Day 2 (November 7, 2001) under AHPC mode with an A/C ratio of 3.0 m/min (10 ft/min) and a carbon injection rate of 0.29 kg/hr (0.65 lb/hr) (corresponding to 24 kg of carbon/million m³ [1.5 lb carbon/million acf]). All the samples and chemical solutions used for recovering mercury were sent back to the EERC for mercury analysis and to look for the source of mercury contamination. Analysis data showed that the 10% nitric acid used for mercury recovery in sampling was contaminated, which resulted in the high mercury concentrations measured in the Ontario Hydro samples collected in Day 1 and 2 tests. A new batch of mercury-free 10% nitric acid was prepared and used for the following sampling tests. In order to validate the sampling results for Days 1 and 2, the mercury concentrations in the sampling solutions were subtracted by the measured mercury concentrations in the corresponding field blank impinger solutions, and the corrected data were reported as approximate mercury concentrations in the flue gas.

As discussed earlier, the Ontario Hydro sampling method provides mercury species information in flue gas as elemental mercury vapor, oxidized mercury, and mercury associated with particulate matter. All the results are presented in the form of µg/Nm³ based on the CVAA analysis results of the impinger solutions, sampling flue gas volume, and dust loading. All of the measured mercury concentrations in the flue gas were corrected to a moisture-free 3% O₂ level to allow a valid comparison at varying O₂ levels.

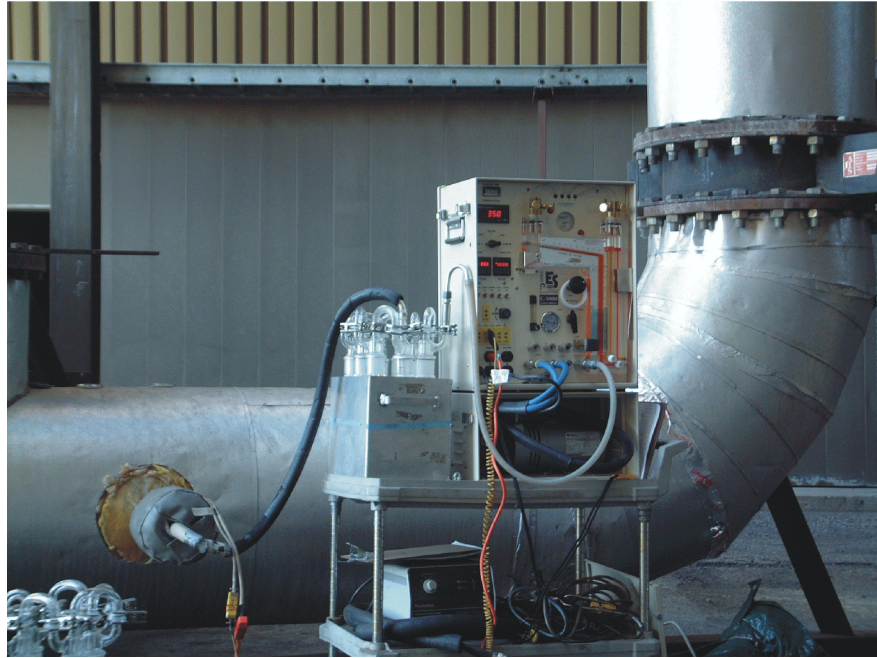


Figure 6. Ontario Hydro sampling train at the AHPC inlet.

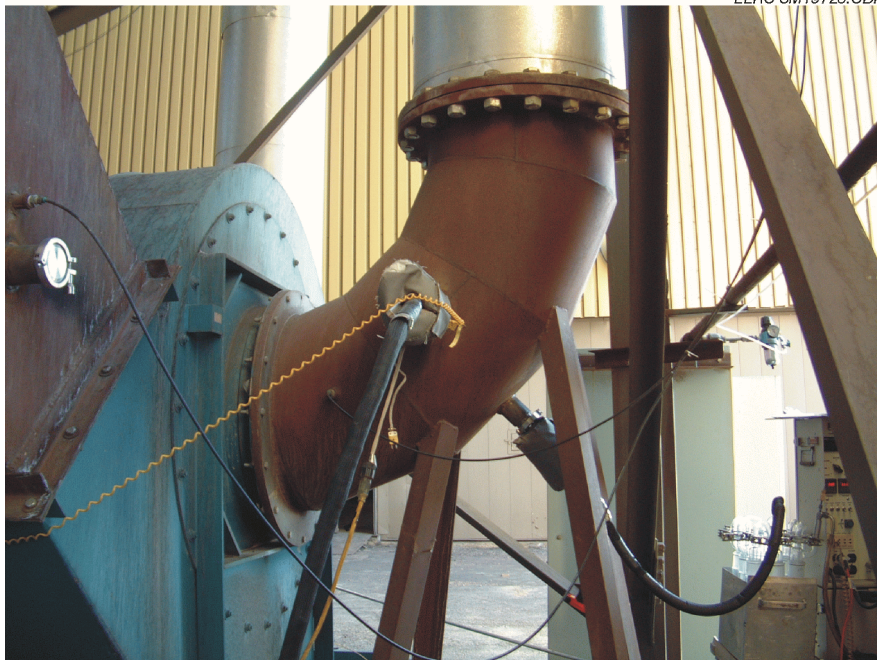


Figure 7. Ontario Hydro sampling at the AHPC outlet.

The dust-loading measurement results at the inlet and outlet of the AHPC system (obtained from Ontario Hydro method) are listed in Table 8, and the corresponding particle collection efficiencies are also calculated and presented in Table 8. The indicated particle collection efficiency ranged from 99.972% to 100%, which represents the level of accuracy that can be achieved by this method with a 2-hr sample. Earlier tests on the Big Stone AHPC where the outlet was sampled for over 15 hours indicated dust loadings in the range of 0.00009 to 0.0002 gr/m³ (0.00004 to 0.00009 gr/dscf). Independent measurements with real-time particle analyzers have also proven the collection efficiency to be better than 99.99%.

Table 8. Dust Loading at the AHPC Inlet and Outlet and the Calculated Collection Efficiency

	Inlet, gr/dscf	Outlet, gr/dscf	Collection Efficiency, %
Day 1-1	1.169	0.000250	99.978
Day 1-2	1.235	0.000191	99.984
Day 2-1	1.324	0.000363	99.972
Day 3-1	0.909	0.000231	99.974
Day 4-1	1.189	1.760E-06	99.999
Day 5-1	0.909	0	100.000
Day 5-2	0.916	8.880E-05	99.990

A summary of mercury analysis results from the Ontario Hydro method is listed in Table 9. The total mercury concentration in the flue gas (present as total mercury concentration at the AHPC inlet) ranged from 10.6 to 13.2 µg/Nm³, which is slightly lower than the theoretical value of 15.1 µg/Nm³ obtained from the coal combustion calculation based on the coal analysis. A possible reason is the underestimated inlet dust loading. However, considering the complexity of mercury analysis, the measured mercury results are close to the theoretical value.

The Day 1 baseline mercury species distributions are plotted as a function of sampling location in Figure 8. At the AHPC inlet, the mercury associated with particulate was 5.91–7.12 µg/Nm³ and the oxidized mercury was 5.2–6.55 µg/Nm³, while the elemental mercury vapor was at a surprisingly low level of 0.87 µg/Nm³. The normalized mercury species distributions, shown in Figure 9, indicate that around 50% of total mercury was associated with the particulate phase, another 43% of total mercury was in the oxidized state, and only about 7% was in the elemental state. The mercury concentrations at the AHPC outlet are also shown in Figure 8. All the mercury associated with the fly ash particles was completely removed from the flue gas because of the extremely high particle collection efficiency (>99.99% based on dust loading measured at the AHPC inlet and outlet). However, gas-phase mercury including elemental and oxidized penetrated the AHPC with virtually no capture, resulting in an elemental mercury concentration of 1–1.23 µg/Nm³ and an oxidized mercury concentration of 4.72–6.46 µg/Nm³ at the outlet, almost the same level as that of the inlet. The normalized mercury distributions at the outlet are also plotted in Figure 9. The collection efficiencies of mercury species by the AHPC system itself are shown in Figure 10. A 100% collection efficiency of mercury associated with fly ash was achieved because of the excellent capture efficiency of particulate by the AHPC unit. For the mercury vapor, results indicate 4.8% of oxidized mercury vapor was removed by the system,

Table 9. Summary of Ontario Hydro Mercury Results, dry flue gas at 3.0% O₂ (µg/Nm³)

		Hg ⁰	Hg ⁺	Hg (Particulate)	Hg (Total)
Day 1	Inlet	0.87	5.2	7.12	13.19
		0.87	6.55	5.91	13.33
	Outlet	1.0	4.72	0	5.72
		1.23	6.46	0	7.69
Day 2	Inlet	1.04	3.04	6.49	10.57
	Outlet	0.75	0	0	0.75
		0.87	0.55	0	1.42
		0.74	0.06	0	0.80
Day 3	Inlet	1.13	5.99	4.32	11.44
	Outlet	0.11	0.27	0	0.38
		0.14	0.46	0	0.6
		0.14	0.05	0	0.19
Day 4	Inlet	0.41	2.64	10.2	13.25
	Outlet	0.21	1.07	0	1.28
		0.13	0.75	0	0.88
		0.13	0.96	0	1.09
Day 5	Inlet	0.62	5.5	5.86	11.98
	Outlet	0.13	0.61	0	0.74
Day 5	Inlet	0.42	3.88	7.83	12.13
	Outlet	0.09	0.54	0	0.63

Day 1 – No carbon injection, AHPC, 3.0 m/min (10 ft/min).

Day 2 – Carbon: 0.65 lb/hr, AHPC 3.0 m/min (10 ft/min).

Day 3 – Carbon: 0.33 lb/hr, pulse jet, 1.5 m/min (5 ft/min).

Day 4 – Carbon: 0.65 lb/hr, AHPC 3.0 m/min (10 ft/min).

Day 5 – Carbon: 0.33 lb/hr, AHPC 1.5 m/min (5 ft/min).

Day 5 – Carbon: 0.33 lb/hr, Pulse jet 1.5 m/min (5 ft/min).

And a ! 28.2% collection efficiency of elemental mercury vapor was observed. However, considering the low inlet Hg⁰ and the blank correction, the outlet Hg⁰ and Hg⁺ concentrations were similar to the inlet values, and the 49.4% overall collection efficiency of mercury by the AHPC without carbon injection was the result of capturing particulate-bound mercury.

On the Day 2 sampling test, the unit was operated in an AHPC mode (70 mA, 58 kV, 3.0 m/min [10 ft/min], 20-min bag-cleaning interval [BCI]), with a carbon injection of 0.29 kg/hr (0.65 lb/hr) (corresponding to 24 kg of carbon/million m³ [1.5 lb carbon/million acf]). Results from one inlet and three outlet Ontario Hydro samples are shown in Figure 11. In the presence of the activated carbon in the flue gas, the outlet mercury emission was reduced to 0 µg/Nm³ of particulate mercury, 0–0.55 µg/Nm³ of oxidized mercury, and 0.74–0.85 µg/Nm³ of elemental mercury vapor. The corresponding collection efficiencies are plotted in Figure 12. Again, the

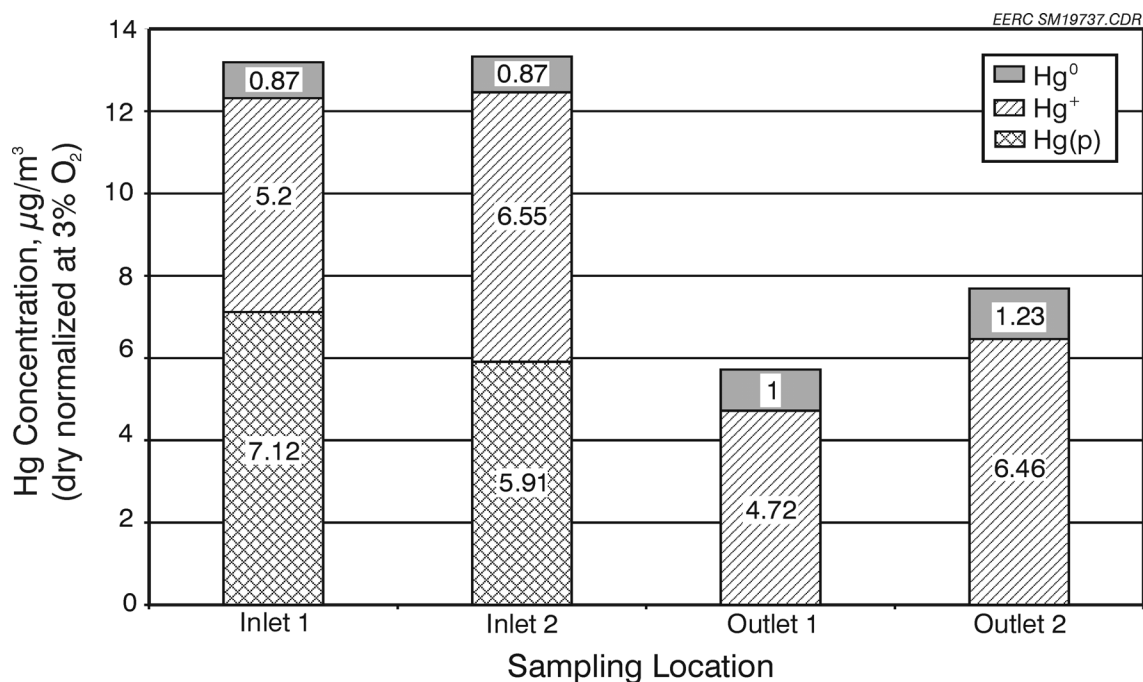


Figure 8. Day 1 – mercury species concentration in flue gas across the AHPC (10 ft/min, 20-minute BCI, multibank cleaning, no carbon injection).

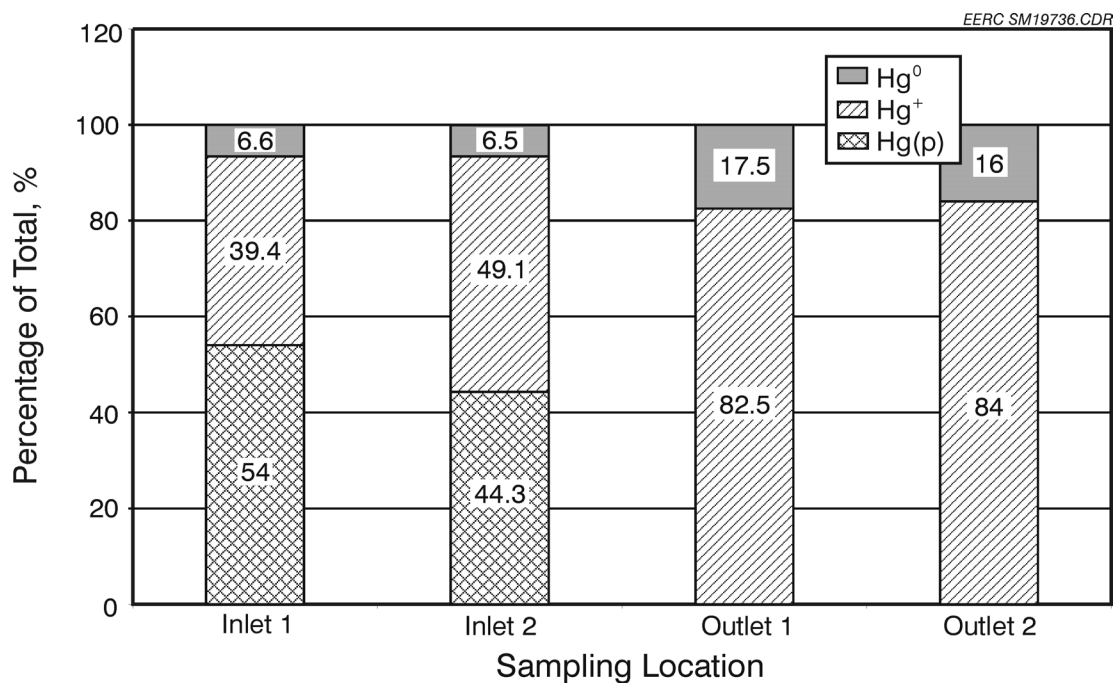


Figure 9. Day 1 – percentage of mercury species distribution in flue gas across the AHPC (10 ft/min, 20-minute BCI, multibank cleaning, no carbon injection).

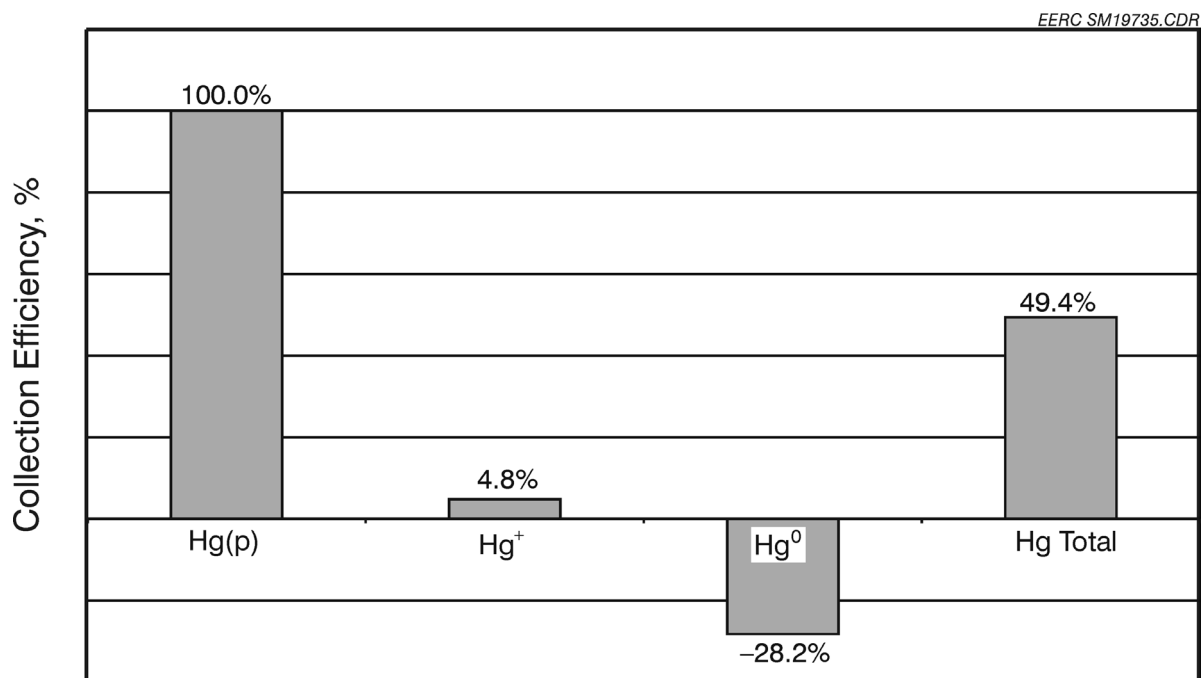


Figure 10. Day 1 – mercury species collection efficiency in AHPC mode (10 ft/min, 20-minute BCI, multibank cleaning, no carbon injection).

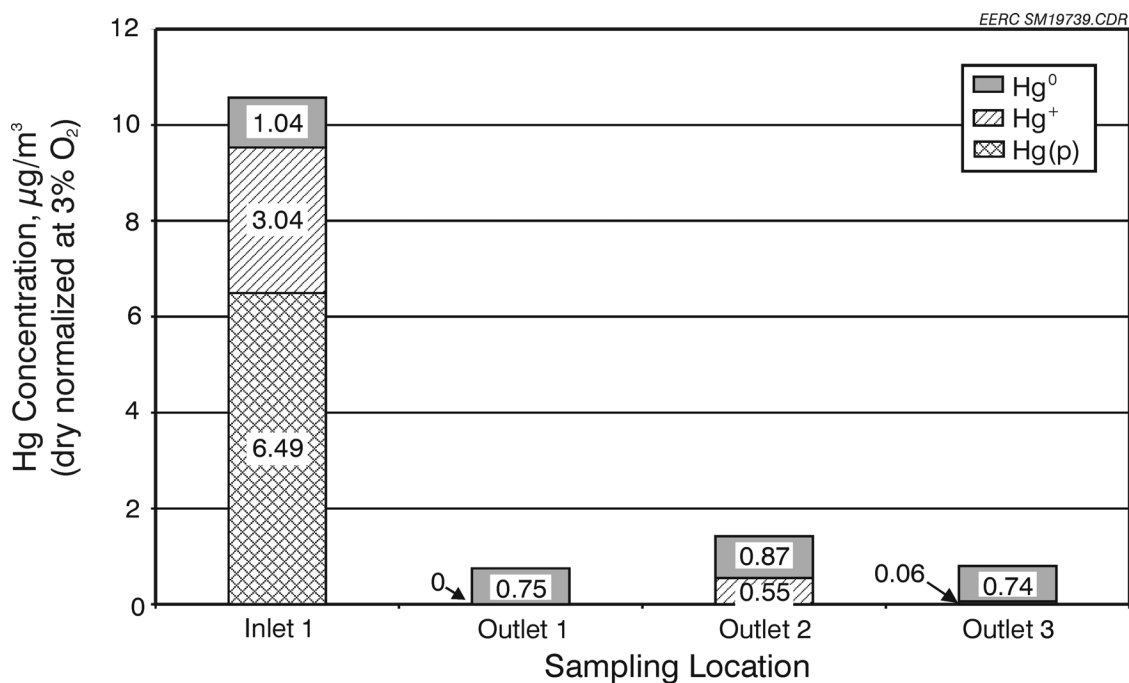


Figure 11. Day 2 – mercury species concentration in flue gas across the AHPC unit in AHPC mode (10 ft/min, 20-minute BCI, multibank cleaning, carbon: 0.65 lb/hr).

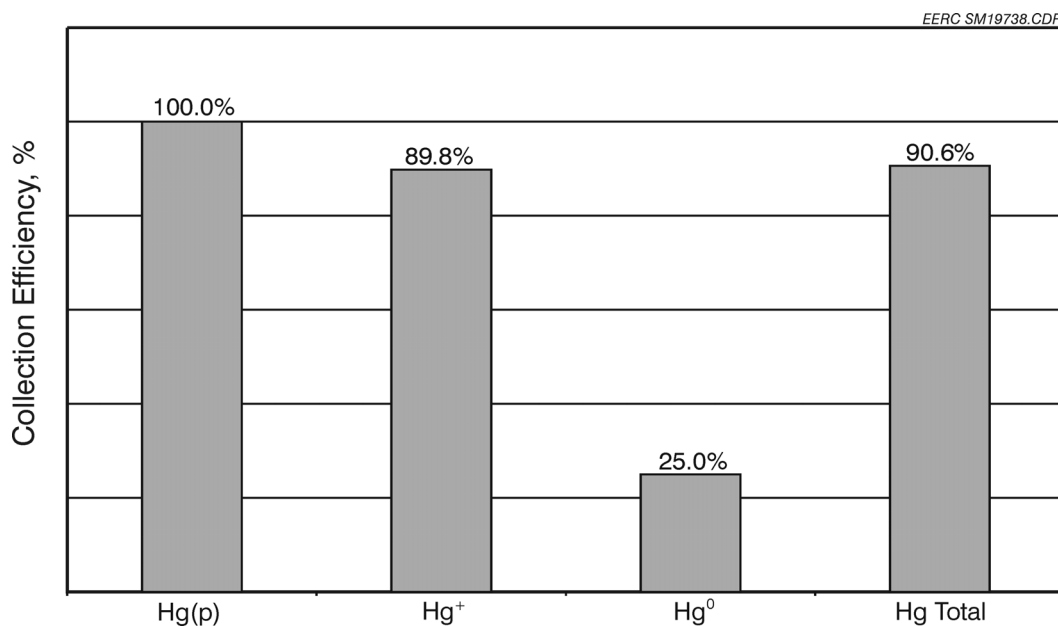


Figure 12. Day 2 – mercury species collection efficiency in AHPC mode (10 ft/min, 20-minute BCI, multibank cleaning, carbon: 0.65 lb/hr).

removal efficiency for particulate-associated mercury was 100%. The oxidized mercury collection efficiency was dramatically increased from 4.8% under no carbon injection to 89.8% under the carbon injection rate of 24 kg of carbon/million m³ (1.5 lb carbon/million acf), showing the DARCO FGD activated carbon efficiently adsorbed the oxidized mercury on the sorbent surface. The indicated elemental mercury vapor collection efficiency was 25%, but because of the low inlet Hg⁰ and blank correction, there is more uncertainty as to the exact removed percentage of Hg⁰. The overall mercury collection of 90.6% compared to 49% without carbon indicates the carbon injection was effective.

On Day 3, the AHPC unit was then operated in pulse-jet mode (without high-voltage power) with a 20-min BCI. In order to keep the pressure drop across the system at a reasonable level, the A/C ratio was reduced to 1.5 m/min (5 ft/min) and the carbon injection rate was correspondingly reduced to 0.15 kg/hr (0.33 lb/hr) to keep the same carbon-to-flue gas ratio of 24 kg of carbon/million m³ (1.5 lb carbon/million acf). The measured mercury species concentrations (one inlet and three outlet samples) are plotted in Figure 13. The inlet mercury species distribution was similar to the previous two days. The outlet mercury was at a very low level in the presence of carbon injection: 0 µg/Nm³ of particle associated mercury, 0.07–0.46 µg/Nm³ of oxidized mercury, and 0.11–0.14 µg/Nm³ of elemental mercury vapor. The corresponding mercury collection efficiencies are plotted in Figure 14, showing removal efficiencies of oxidized mercury and elemental mercury of 95.6% and 88.5%, respectively, and an overall mercury capture efficiency up to 96.6%, which is somewhat better than the 90.6% achieved in the Day 2 sampling test. For Day 3, the outlet values should be more accurate because no blank correction was needed. Longer residence time at the reduced A/C ratio of 1.5 m/min (5 ft/min) and a lower temperature may have contributed to the somewhat lower mercury emissions compared to Day 2.

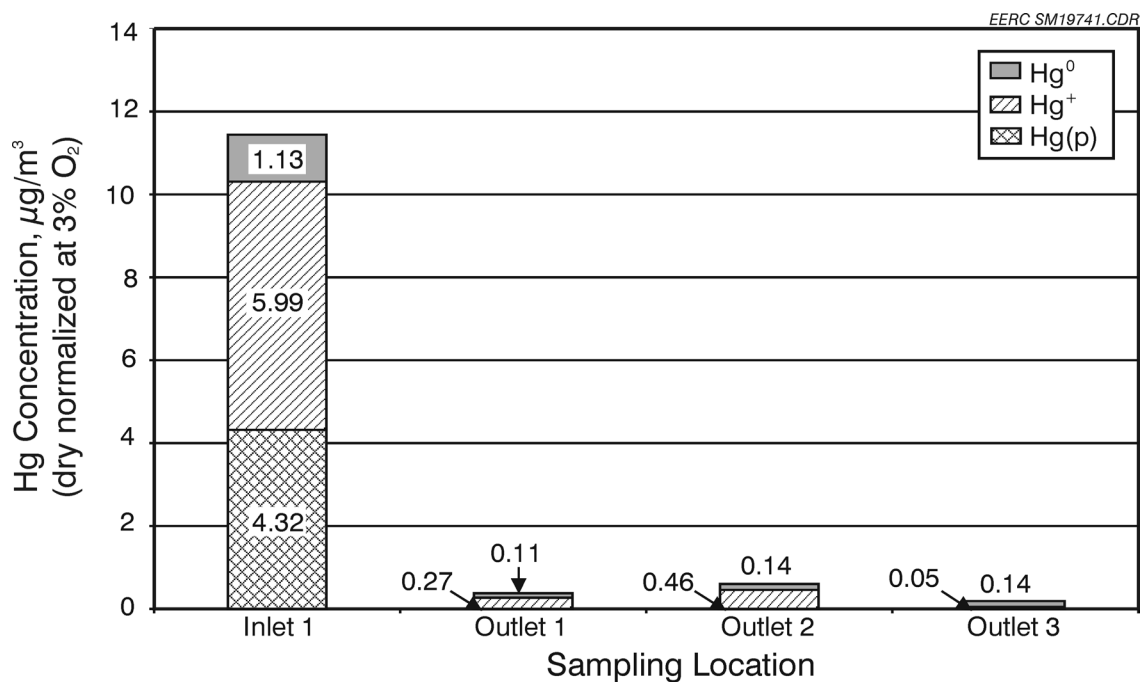


Figure 13. Day 3 – mercury species concentration in flue gas across the AHPC unit in pulse-jet mode (5 ft/min, 20-minute BCI, multibank cleaning, carbon: 0.33 lb/hr).

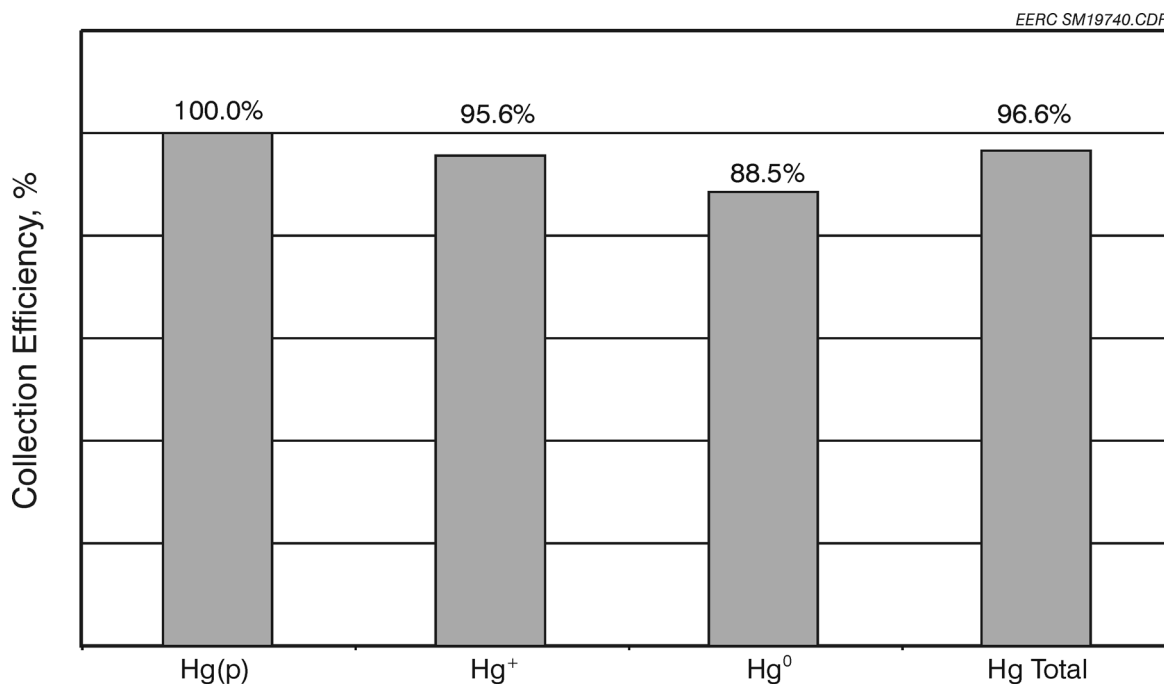


Figure 14. Day 3 – mercury species collection efficiency in pulse-jet mode (5 ft/min, 20-minute BCI, multibank cleaning, carbon: 0.33 lb/hr).

The Day 4 sampling test was a repeat of the Day 2 test (AHPC mode, 20-min BCI, 3.0 m/min [10 ft/min] of A/C ratio, and 0.29 kg/hr [0.65 lb/hr] carbon injection rate). The mercury concentrations and collection efficiencies (shown in Figures 15 and 16) are in good agreement with the results obtained in the Day 2 test. The total mercury collection efficiency was 91.8%, almost the same as the 90.6% achieved in the Day 2 test, and the removal efficiency for oxidized mercury and elemental mercury was 64.0% and 61.8%, respectively.

For Day 5, the unit was operated with carbon injection in both AHPC and pulse-jet modes at the same A/C ratio of 1.5 m/min (5 ft/min). The tests provided a better comparison between the two operating modes because the residence time and temperature were constant. The measured mercury concentrations under the two operating modes are plotted in Figure 17. The total inlet mercury concentration was 11.98 $\mu\text{g}/\text{Nm}^3$ in AHPC mode and 12.13 $\mu\text{g}/\text{Nm}^3$ in pulse-jet mode, indicating constant inlet conditions. The outlet mercury was also similar for both operating modes. The collection efficiencies are plotted in Figure 18, showing the removal efficiencies for oxidized, elemental, and total mercury were the same for both modes. However, the system was only operated for 2 hours for each test, and more long-term experiments are necessary to verify these results.

During the week, the sorbent was injected only during the day, and after completing the mercury sampling, the carbon injection was shut off overnight to allow the unit to return to baseline conditions. Four hopper ash samples were collected each day as a function of time except for the first day and the fifth day when two samples and three samples were collected, respectively. The first sample usually was regarded as baseline ash, and the rest represented ash samples from the carbon injection tests. The hopper ash samplers were then acid-digested and measured for mercury concentration. The results are presented in Table 10. For comparison, the filter ash mercury from the inlet Ontario Hydro samples is also reported in Table 10. For the Day 1 baseline test, both the inlet filter ash and hopper ash had almost the same mercury concentration at approximately the same operating time. With carbon injection, the mercury concentration in the hopper ash gradually increased, showing the mercury vapor was absorbed on the activated carbon and was removed from the flue gas by the filter bags. A fly ash sample collected in the thimble filter used in CEM sampling at the inlet location was also analyzed for mercury concentration and is shown in Table 10. The mercury concentration of 8.22 $\mu\text{g}/\text{Nm}^3$ on the CEM filter fly ash was much higher than that of the hopper ash. One possible reason could be that the sampling nozzle was pointing downstream so the fine fly ash collected in the filter by nonisokinetic sampling had a greater enrichment of mercury compared to that of larger size fly ash particles. Another factor could be that this filter was continually used over a whole day so the extended exposure time may lead to higher mercury adsorption.

The mercury concentrations for the AHPC hopper ash samples along with percent loss on ignition (LOI) shown in Table 10 indicate a general trend of increasing values with the carbon injection, as would be expected. However, because of the varying baseline values, it is not possible to complete a good mass balance. For the measured inlet dust loading, the expected increase in carbon in the fly ash (for the given carbon injection rate) is about 1.6%. The LOI data from Days 4 and 5 are in reasonable agreement with this level of increase. The varying baseline LOI levels and the short-term tests do not allow for a better mass balance closure. The morning

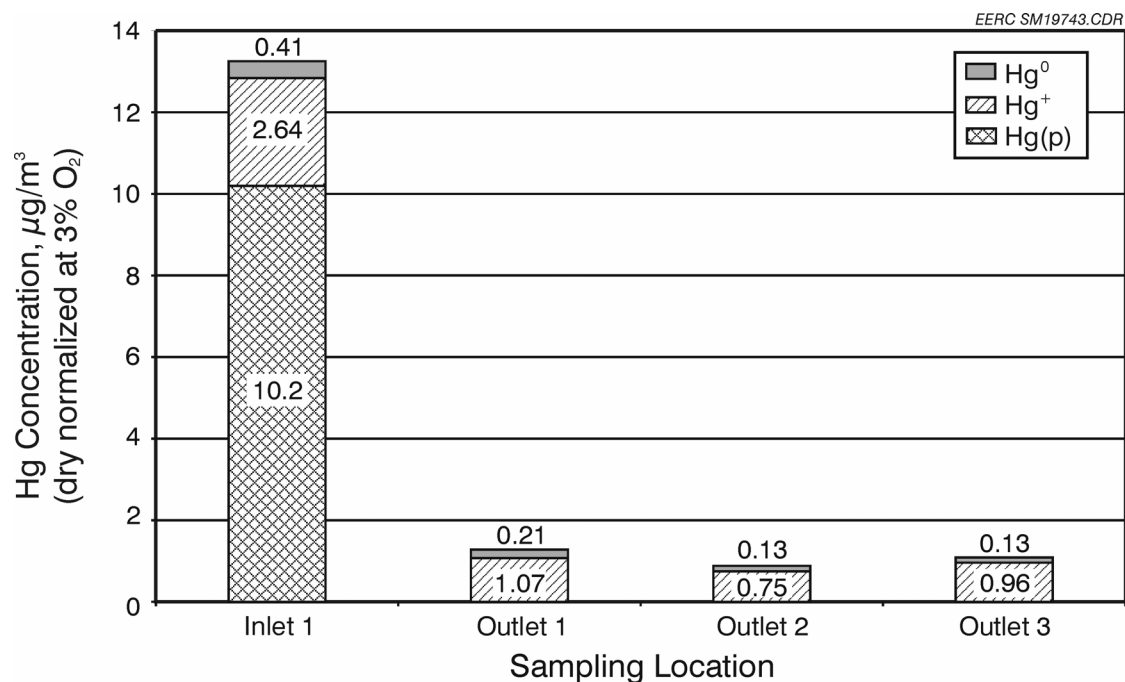


Figure 15. Day 4 – mercury species concentration in flue gas across the AHPC unit in AHPC mode (10 ft/min, 20-minute BCI, multibank cleaning, carbon: 0.65 lb/hr).

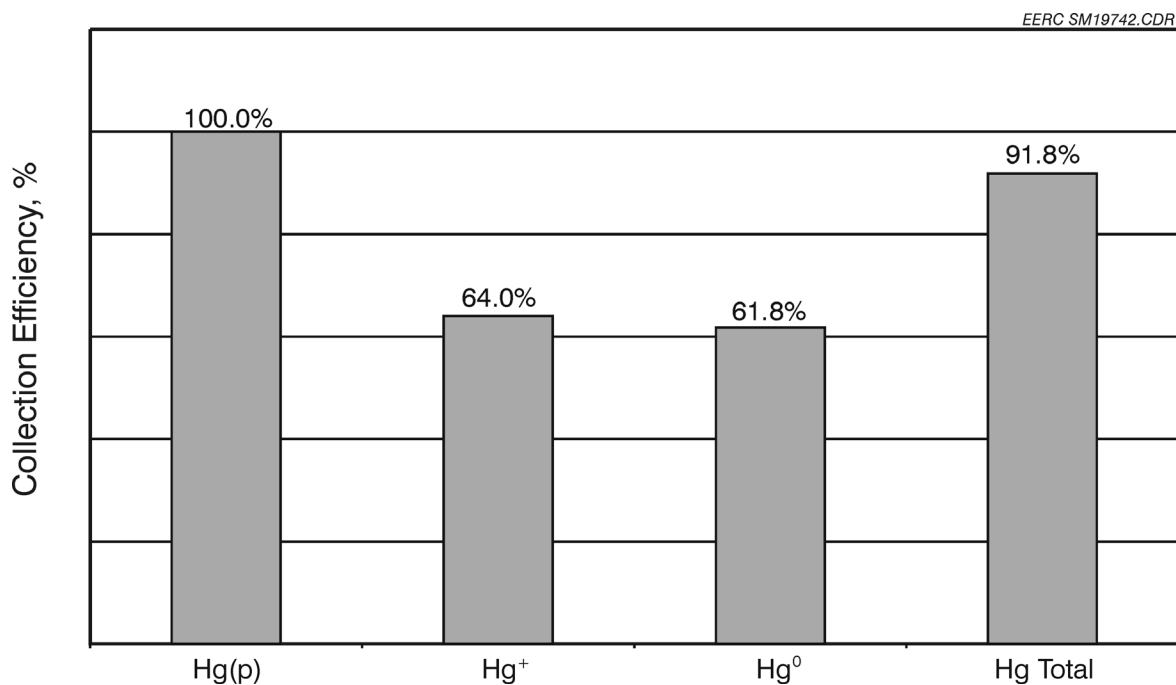


Figure 16. Day 4 – mercury species collection efficiency in AHPC mode (10 ft/min, 20-minute BCI, multibank cleaning, carbon: 0.65 lb/hr).

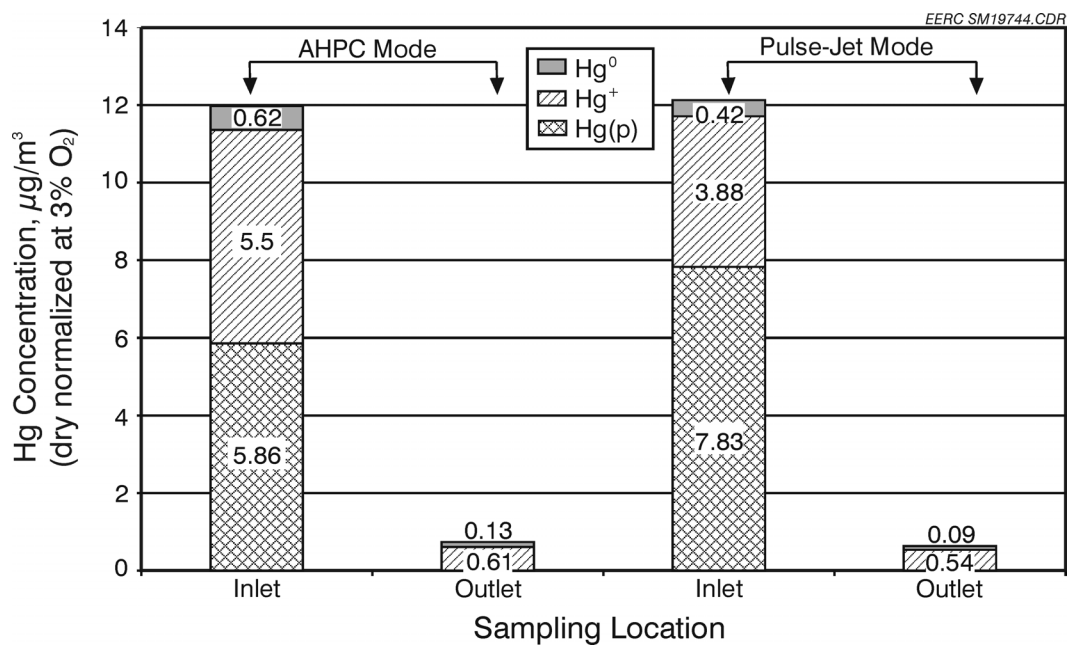


Figure 17. Day 5 – mercury species concentration in flue gas across the AHPC unit at Big Stone in both AHPC and pulse-jet mode.

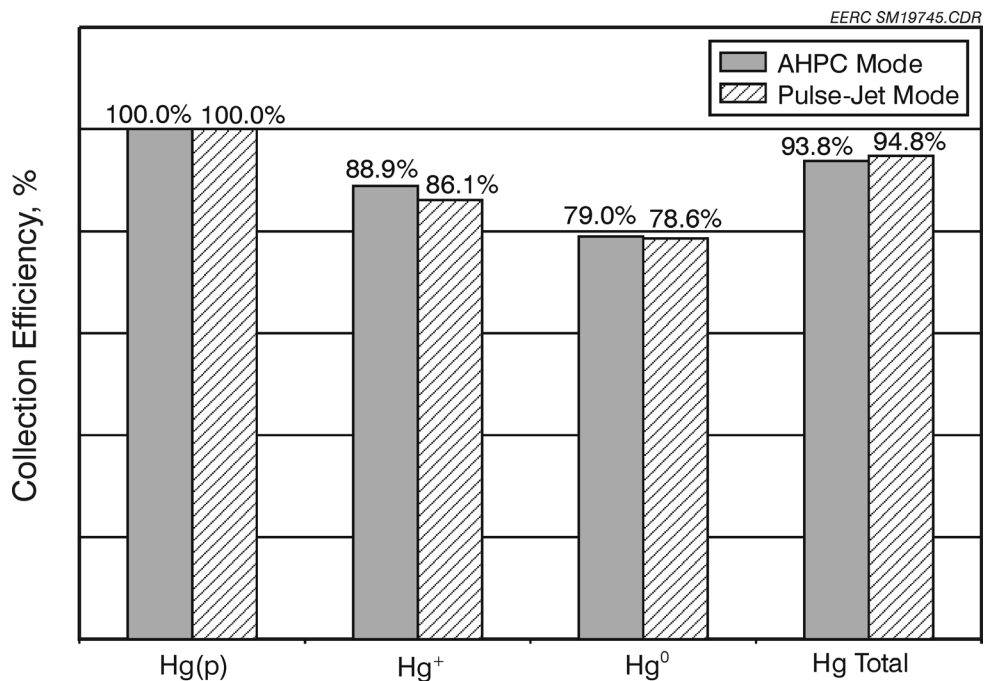


Figure 18. Day 5 – mercury species collection efficiency under AHPC and pulse-jet mode.

Table 10. Mercury Concentration in Fly Ash

Test Day	Sample Type	Time Sample Taken	Hg Concentration, $\mu\text{g/g}$	% LOI
Day 1	Hopper Ash Baseline	11:01	1.84	
Day 1	Hopper Ash Baseline	14:00	1.53	0.48
Day 1	Inlet Filter	9:20–11:20	1.98	
Day 1	Inlet Filter	12:05–14:05	1.58	
Day 2	Hopper Ash Baseline	7:10	1.34	0.79
Day 2	Carbon Injection AHPC	10:02	2.58	
Day 2	Carbon Injection AHPC	12:01	2.74	
Day 2	Carbon Injection AHPC	14:00	3.06	1.56
Day 2	Inlet Filter	8:00–10:00	1.67	
Day 3	Hopper Ash Baseline	7:18	1.67	1.86
Day 3	Carbon Injection Pulse Jet	11:00	3.58	
Day 3	Carbon Injection Pulse Jet	14:04	3.94	
Day 3	Carbon Injection Pulse Jet	16:01	3.62	2.15
Day 3	Inlet Filter	10:23–12:23	1.59	
Day 4	Hopper Ash Baseline	7:20	1.64	0.71
Day 4	Carbon Injection AHPC	11:01	2.71	
Day 4	Carbon Injection AHPC	13:04	2.80	
Day 4	Carbon Injection AHPC	16:01	3.36	1.90
Day 4	Inlet Filter	9:00–11:00	2.89	
Day 5	Hopper Ash Baseline	7:18	3.09	1.67
Day 5	Carbon Injection AHPC	10:01	3.46	
Day 5	Carbon Injection Pulse Jet	13:01	3.90	2.45
Day 5	Inlet Filter	8:00–10:00	2.18	
Day 5	Inlet Filter	11:00–13:00	2.89	
Day 4	Inlet Filter from CEM	8:00–19:00	8.22	

baseline ash samples were collected after a time without carbon injection, but no attempt was made to clean the AHPC hopper of residual ash between tests so some mixing of the hopper ash from different tests could have occurred.

3.7 Mercury CEM Results

The total mercury vapor concentration and elemental mercury vapor concentration at the AHPC inlet and outlet were continuously monitored on Days 3–5 by a PS Analytical Sir Galahad analyzer. Since only measuring mercury vapor, a nonisokinetically sample of flue gas was pulled through a thimble filter to remove the fly ash. The particle-free flue gas was then passed through a conversion unit (as shown in Figure 19) where the oxidized mercury could be reduced to elemental state, depending on which side of the pretreatment system the flue was passed through. The mercury exiting the conversion unit was introduced into the PS Analytical Sir Galahad (shown in Figure 20) for elemental or total mercury concentration measurement.

The elemental and total mercury concentrations monitored at the AHPC inlet during the Day 3 test are plotted as a function of operating time and shown in Figure 21. The inlet elemental mercury was around $0.39 \mu\text{g}/\text{Nm}^3$, only accounting for 8.4% of the measured total mercury vapor concentration of $4.62 \mu\text{g}/\text{Nm}^3$, which agreed with the Ontario Hydro results. In the presence of activated carbon in flue gas, the total mercury concentration at the outlet was about $0.54 \mu\text{g}/\text{Nm}^3$ (also shown in Figure 21), and the elemental mercury concentration in flue gas was below the CEM detection limit, which was in reasonable agreement with the results from the Ontario Hydro method. They both showed that most of the inlet mercury vapor in the flue gas was in the oxidized state and excellent mercury capture in the presence of the activated carbon. At 16:00, the carbon injection was shut down while the outlet was continually monitored for mercury. As seen in Figure 21, the total outlet mercury concentration gradually increased and reached the same level as that of the inlet. The observed slow increase of mercury concentration at the outlet was likely caused by the residual activated carbon in the AHPC chamber after the carbon injection system was shut down.



Figure 19. Conversion system CEM mercury sampling.

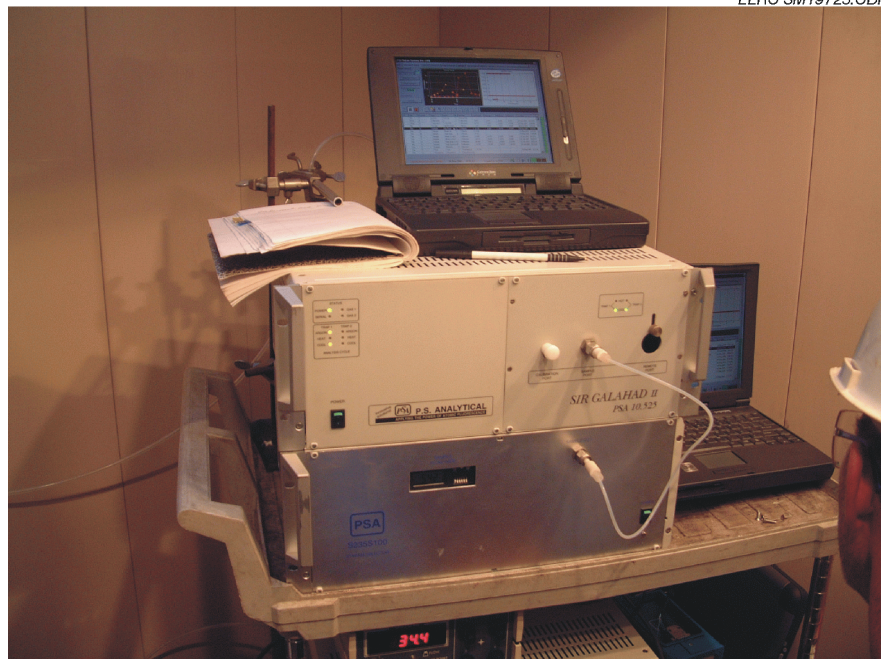


Figure 20. PS Analytical mercury analyzer.

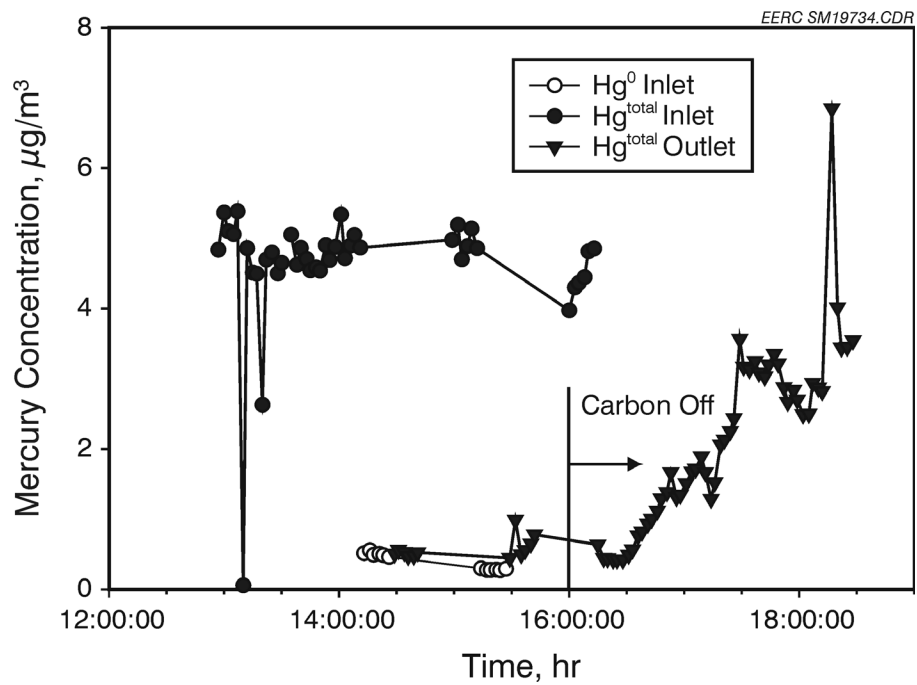


Figure 21. Hg species measurement by CEM – Day 3.

Figure 22 shows the Day 4 total and elemental mercury concentrations at both the AHPC inlet and outlet when the unit was operated with carbon injection. The total inlet mercury vapor concentration varied from 2.78 to 3.54 $\mu\text{g}/\text{Nm}^3$, with an average value of 3.09 $\mu\text{g}/\text{Nm}^3$, which was very close to the 3.05 $\mu\text{g}/\text{Nm}^3$ from Ontario Hydro analysis. Again, a very low percentage of elemental mercury was observed at the AHPC inlet. The total mercury concentration at the outlet was maintained around 0.6 $\mu\text{g}/\text{Nm}^3$, showing an efficient mercury vapor removal (including both elemental and oxidized state) due to the activated carbon.

On the Day 5 test, the unit was operated under both AHPC mode and pulse-jet mode to compare the effectiveness of carbon injection on mercury capture at the same A/C ratio and temperature. As shown in Figure 23, the total mercury concentration at the inlet was around 2.6 $\mu\text{g}/\text{Nm}^3$ during the tests, while the total mercury concentration at the outlet was about 0.36 $\mu\text{g}/\text{Nm}^3$ under both operating modes. The experimental data by the CEM analysis, which were slightly lower than the measured results from Ontario Hydro method, showed both the AHPC and pulse-jet modes have identical collection efficiency of mercury species.

3.8 AHPC Operational Summary

During the 5-day sampling test, the AHPC unit was set up at a fixed 20-min BCI with an A/C ratio of either 1.5 m/min (5 ft/min) or 3.0 m/min (10 ft/min). The carbon injection rate of 24 kg/million m^3 (1.5 lb/million acf) is equivalent to a dust inlet loading of 0.023 g/actual m^3 or 0.034 g/standard m^3 (0.01 gr/acf or 0.015 gr/scf). Compared to the average inlet fly ash dust loading of 2.2 g/standard m^3 (0.96 gr/scf), this represents 1.6% of the dust loading and would not be expected to affect the AHPC pressure drop. From the pressure drop and drag data with and without carbon injection, there was no effect of the carbon injection on AHPC operation.

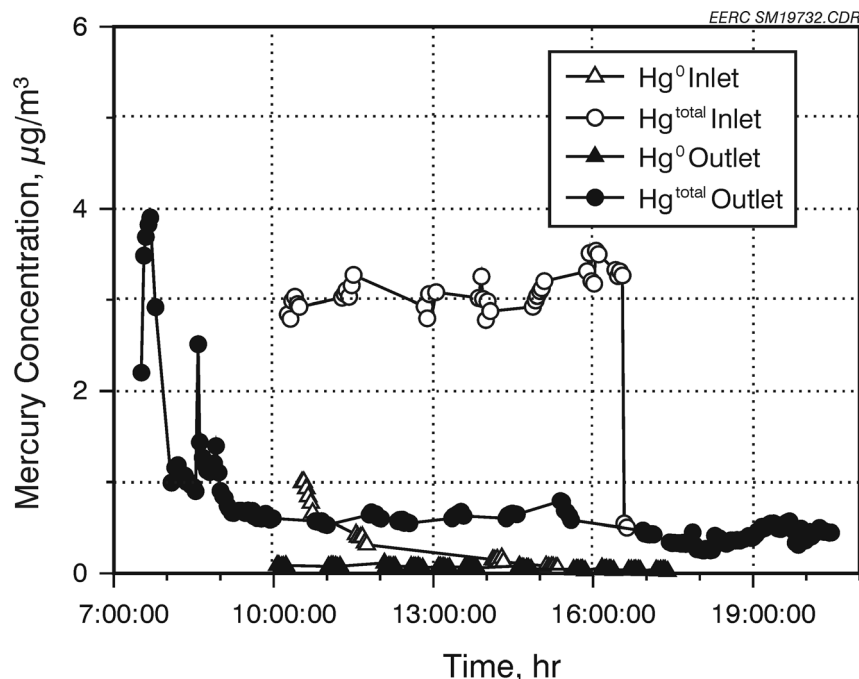


Figure 22. Hg species measurement by CEM – Day 4.

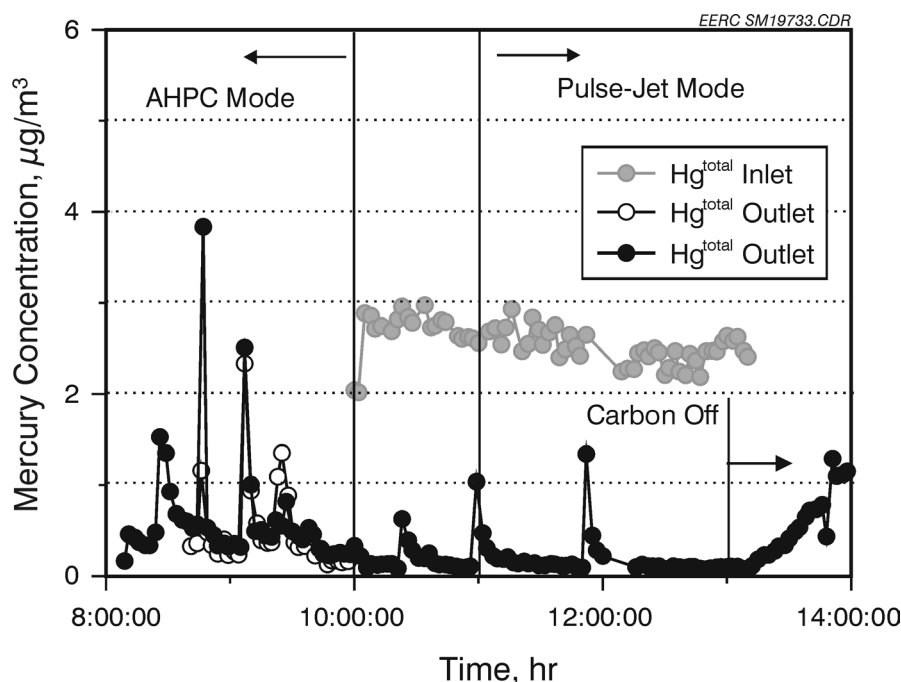


Figure 23. Hg species measurement by CEM – Day 5.

4.0 CONCLUSIONS AND DISCUSSION

- The average inlet total mercury concentration of $12.3 \mu\text{g}/\text{Nm}^3$ (dry @3% O_2) was slightly below the theoretical value of $15 \mu\text{g}/\text{Nm}^3$. One possible reason for the difference is that the inlet sample location was at a point where the inlet dust loading may be somewhat biased low. Since about half of the mercury was particulate bound, a low dust loading measurement would also result in a low total mercury measurement. For example, if the dust loading was 30% low, this would translate to a 15% low bias in the total inlet mercury.
- The average inlet mercury speciation for seven samples was 55.4% particulate bound, 38.1% oxidized, and 6.4% elemental. The high level of particulate-bound mercury and oxidized mercury was somewhat surprising because for western PRB coals lower levels of particulate-bound mercury and oxidized mercury are more typical. However, significant capture of mercury by the fly ash has been observed in previous EERC pilot tests as well as a number of coal-fired plants burning western fuels. Possible factors that determine the level of particulate-bound and oxidized mercury include coal type, boiler type, HCl (as well as other flue gases), temperature, and amount of carbon in the fly ash. The current level of understanding of how these factors work together is insufficient to explain the observed mercury speciation for individual plants.
- A carbon injection rate of 1.5 lb/million acf corresponds to a carbon-to-mercury ratio of approximately 2500 for the measured inlet mercury. With this carbon injection rate, from 91% to 97% total mercury collection efficiency was achieved compared to 49% removal for the

baseline case. Even though the carbon addition rate was low, the carbon was highly effective at removing mercury. The data show that the carbon was effective at removing both elemental and oxidized mercury.

- Mercury removal with carbon removal in AHPC mode was 91% and 92% on Days 2 and 4 compared to 97% on Day 4 in pulse-jet mode. At first glance, this would seem to indicate that the pulse-jet configuration is better than the AHPC for mercury removal. However, in the pulse-jet mode, the residence time in the duct and chamber was twice as long and the temperature was also about 11EC (20EF) lower because of the lower flow rate. Both the longer residence time and lower temperature would be expected to lead to better mercury capture. On Day 5, the unit was operated in both modes at the same flow rate, which resulted in 94% capture in AHPC mode and 95% capture in pulse-jet mode. From these results, it can be concluded that both modes provided excellent mercury capture, at least for short-term tests, and there was no difference in mercury capture between the two modes. The conditions that produce the best collection efficiency with activated carbon are not well known. Previous pilot and field data indicate that the level of mercury capture with carbon is highly dependent on the coal type, other flue gases present, temperature, contact geometry, and residence time, but no model is available that can employ these factors to predict the level of capture for a specific configuration.
- These short-term tests are highly encouraging because they prove that excellent mercury removal can be achieved with very low addition rates of carbon injected upstream of the AHPC. Further testing is needed to demonstrate that the high level of mercury removal can be maintained over the longer term and that the carbon injection will not have any adverse effect on the longer-term operation of the AHPC. Since the conditions that lead to good mercury capture with carbon are not well known, at this point the results should not be generalized to other coals or plants.